Impact of different land management on soil spiders (Arachnida: Araneae) in two Amazonian areas of Brazil and Colombia

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Abstract. The global demand for different land-use practice commodities in the Amazonia is growing, and this region is increasingly affected by the impacts of land management. The aim of this study was to evaluate the influence of land-use intensification on soil spider assemblages from six different land-use systems in Colombia and Brazil. The systems were fallows after crops and pastures, forest, crops, pastures and plantations. Spider species richness and density decreased with increasing farming management intensity. A principal component analysis (PCA) showed forests and fallows were separated from systems with stronger anthropogenic soil disturbance. The relationships of ten spider guilds differed significantly between land-uses, suggesting that they can be a reliable parameter for studies of ecological indicators.

Keywords: Macroecology, agroecosystems, land-use, guilds, ecological indicators

Soil is one of the most diverse habitats on earth (Giller et al. 1997; Wolters 2001; Decaëns et al. 2006). Unfortunately, the soil diversity in Amazonia is threatened by the growing global demand for agricultural commodities produced in this region and also by increasing deforestation (Laurance et al. 2002). Additionally, climate change can result in drought and forest fires (Laurance et al. 2002). Change in soil use in Amazonia is currently intense, and the conversion of native forest to agricultural practices or pasture is the main disturbance effect impacting the remaining native forests (Fearnside 2005, 2006). The social and economic importance of this kind of agriculture is well recognized (Alexandratos 1995), but its environmental impact is not satisfactorily known. Usually there is a consensus among researchers as to the negative effects of habitat modification (e.g., deforestation by ranchers and farmers) on diversity of native plant and animal species in Amazonia (e.g., Laurance et al. 2000; Perner & Malt 2003; Soares-Filho et al. 2006). Understanding changes that directly influence these processes is important for local people, whose livelihoods depend on agriculture practices or pasture areas. In fact, determining the composition of soil macrofauna is crucial to understanding the ecological complexity of these assemblages (Franklin et al. 2005; Decaëns et al. 2006; Lavelle et al. 2006; Decaëns 2010). Several organisms of the soil fauna (e.g., arthropods) have been proposed as bioindicators of soil quality and sustainability (Marc et al. 1999; Willet 2001; Lawes et al. 2005).

Arthropods are the most diverse group of animals, inhabiting most habitats on Earth (Hawksworth & Bull

2006). Furthermore, arthropod diversity may be higher in cultivated areas than in non-cultivated areas (e.g., secondary forest), suggesting that arthropods are good candidates for biodiversity correlates (see Duelli & Obrist 1998). Arachnids represent approximately 2% of the described species worldwide (Adis 2002) and are conspicuous components of agricultural landscapes (Samu et al. 1999). Given their prominence, several authors have studied the effect and relative importance of local environmental factors on arachnids (mostly spiders) in agroecosystems. Studies of spiders deal with the potential use of these animals for limiting arthropod pests through predation (Greenstone & Sunderland 1999; Hodge 1999; Marc et al. 1999; Riechert 1999; Sunderland 1999; Maloney et al. 2003; Nyffeler & Sunderland 2003; Harwood et al. 2004), competition and interactions (Marshall & Rypstra 1999; Wise et al. 1999), guild structure (Gibson et al. 1992; Uetz et al. 1999), agrobiont species (Samu & Szinetar 2002; Pekár & Haddad 2005; Thorbek & Topping 2005; De Meester & Bonte 2010), and diversity and distribution (Duelli & Obrist 1998; Samu et al. 1999; Seyfulina 2010). All these studies showed that spiders are useful as potential ecological indicators and natural enemies of pests, since the composition and species richness in different land management areas depend on disturbance levels, regional populations of spider species composition and the spatial and temporal scales of a given study. However, little information is available on the effects of different forest management regimes on the composition of arachnid assemblages (e.g., Downie et al. 1999; Rypstra et al. 1999; Jeanneret et al. 2003). In addition, in Amazonia the consequences of different land management techniques on this group are rarely studied.

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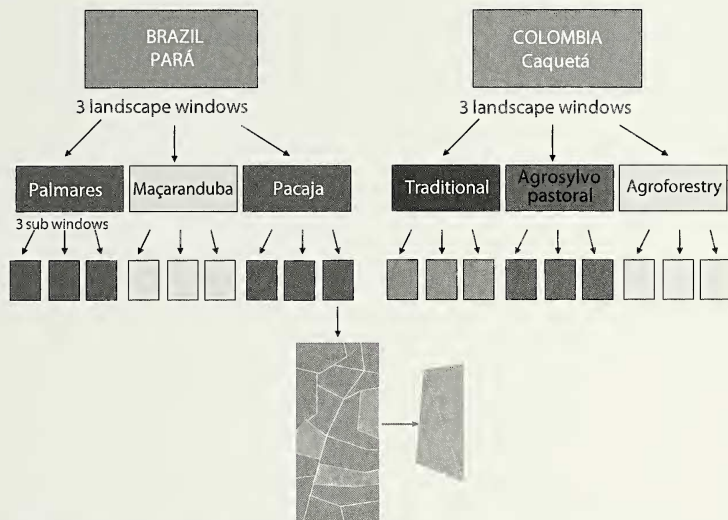
Figure 1.—Site selection, showing sampling design for each study area (modified from Lavelle et al. 2010). Area names match those identified in the text (study area and site selection).

The purpose of this study was to assess the impacts of landscape management on spider distribution patterns by sampling two contrasting regions in a large-scale soil ecosystem project. It was also to evaluate the relationships between spider biodiversity parameters in primary forests and in a wide range of derived systems of land management. We tested the hypotheses that spider species richness increases with decreasing management impact, and that overall spider assemblages are suitable as reliable ecological indicators of restoration effects in disturbed landscapes (Perner & Malt 2003).

METHODS

Study area and site selection.—The experiment was established in two Amazonian areas with different plant coverage, one relatively recently colonized (10–15 yr ago) in the state of Pará, northeastern Brazil and another colonized 60 yr ago in the Department of Caquetá, southwestern Colombia. Both study areas were separated into three landscapes (windows) with different deforestation ages and/or different land management structure.

Each window was formed by three replicate groups (sub-windows) containing 17 farms. Three farms were selected in each sub-window, and each selected farm was divided in five sampling points (sites) located 200 m apart along a diagonal transect (Fig. 1). We sampled 54 farms and 270 sites (135 sites in each country).

The landscape mosaic for all areas was analyzed using satellite images - coordinates of the windows in UTM projection, zone 22S, WGS84 for Macaranduba: 682382.74 / 9469861.49; Pacaja: 494874.75 / 9586676.06; Palmares: 627813.87 / 9351874.23, in UTM projection, zone 18N,

WGS84 for Traditional: −2316945.11 / 10179721.63; Agro-sylvopastoral: −2335962.87 / 10176406.04; Agroforestry: −2351790.15 / 10163206.21. Six land-use systems were identified after field confirmation: forest (F; preserved or rationally exploited forests); fallows after crop (FAC; secondary forest developed in abandoned crops dominated by native grasses, vegetables and weeds); fallows after pasture (FAP; secondary forests developed in abandoned pastures dominated by herbs and shrubs); pastures (Past; areas dominated by *Brachiaria* ssp., invaded by "babaçu", an Amazonian palm tree; Arecaceae: *Orbygnia* sp. or other trees); crops (Cr; shifting cultivation of cassava (manioc), rice or maize crops) and plantations (Pl; cocoa, rubber tree, agroforestry systems) (see Marichal et al. 2010, Table 1). Average annual rainfall in the Brazilian sites is 1775.5 mm per annum (p.a.) in Pacajá, 1881.4 mm/p.a. in Maçaranduba, and 2452.6 mm/p.a. in Palmares, with a mean annual temperature of 28.3° C. In the Colombian sites the average annual rainfall is 4676.0 mm/p.a., with a mean annual temperature of 27.8° C.

Spider sampling.—Spiders were sampled between April and June 2008, during the dry season. The sampling methodology used to collect soil and litter spiders was based on the Tropical Soil Biology and Fertility Program (TSBF) method (Anderson and Ingram 1993), which consists of digging one central soil monolith (25 cm long, 25 cm wide and 20 cm deep) and two additional monoliths with 25 × 25 × 30 cm dug 5m east and west, respectively, from the central monolith on each of the 270 sites. A total of 810 monoliths was taken and hand sorted. Thus, one sampled unit was composed of three monoliths. The macrofauna was hand-sorted in the field, and the spiders were stored in 80% alcohol. In the laboratory, the spiders were counted, and the adults were sorted to morphospecies and

Table 1.—Land-use systems observed in Brazil and Colombia sampling areas. Sub-windows labeled as letters followed by numbers.

		Brazil									Colombia								
Country		Maçaranduba			Pacajá			Palmares			Agroforestry			Agrosylvopastoral			Traditional		
Window / Sub-window		BMB1	BMB2	BMB3	BPC1	BPC2	BPC3	BPR1	BPR2	BPR3	CAF1	CAF2	CAF3	CSP1	CSP2	CSP3	CTR1	CTR2	CTR3
Forests	Conserved or exploited forests	3	1	7	4	9	10	5	5	5	0	0	0	0	0	0	0	0	0
Fallows after crop	Secondary forests developed in abandoned crops	3	6	1	3	2	0	0	1	1	0	0	0	0	0	0	0	0	0
Fallows after pasture	Secondary forests developed in abandoned pastures	2	1	0	2	0	1	0	3	4	5	3	1	4	3	2	0	0	1
Pastures	Pastures with *Brachiaria* ssp., or other trees	7	7	6	3	2	2	5	5	1	2	6	10	8	11	13	15	14	13
Crops	Cassava, rice or maize crops	0	0	1	2	0	1	5	1	4	0	0	0	0	0	0	0	0	0
Plantations	Cacao, rubber-tree, agro-forestry systems	0	0	0	1	2	1	0	0	0	8	6	4	3	1	0	0	1	1

identified. The spiders were classified by assemblage guilds and to provide trustworthy for the results, all the analyses were based only on adults (i.e., individuals susceptible to correct identification). The voucher specimens are deposited in the collection of Museu Paraense Emílio Goeldi in Belém, Pará, Brazil (A.B. Bonaldo, curator).

Spider guild establishment.—We followed the classic definition of guilds by Root (1967). Our designation of spider guilds was based on ecological characteristics obtained during fieldwork, observation, biology, taxonomy and additional literature reviewed (i.e., Coddington et al. 1996; Uetz et al. 1999; Höfer & Brescovit 2001; Dias et al. 2010).

Data analysis.—Monte-Carlo test simulations were calculated to assess the significant differences of spider interactions with land use. A Principal Component Analysis (PCA) was performed to verify differences in the composition of spider guilds among land-use systems. The PCA was carried out on a matrix composed of 270 sites and 10 spider guilds. We assigned spiders to ecological categories rather than species, because most species were rare and a great number of zero values in the tables would invalidate the PCA analysis. The data were subjected to natural logarithmic transformation ln $(x + 1)$ to reduce the influence of common species and differences in total site abundance in determining community patterns (see Keene 1995). Statistical analyses were conducted using R version 2.12 (R Development Core Team 2009), package ade4 (Chessel et al. 2004; Dray & Dufour 2007; Dray et al. 2007).

RESULTS

A total of 1906 individuals, including 178 individuals in Palmares, 344 in Maçaranduba, 143 in Pacajá, 459 in Traditional, 340 in Agrosylvopastoral, and 442 in Agroforestry was collected. The adults corresponded to 206 individuals and 101 morphospecies belonging to 25 families. Median species richness was 1.5 species in fallows and forests, with lower values observed in crops, pastures and plantations (0.4, 0.2, and 0.1, respectively: Fig. 2a); average densities of spiders varied from 1.1 individuals/m² in plantations to 7 individuals/ m² in forest, with intermediate values in crops and fallows (Fig. 2b). The results of the analysis of the ten spider guilds (Table 2) collected on each land-use system were subjected to PCA. The correlation circle built with the first two factors represented 28.2% of the total variance (F1 with 15.9% and F2 with 12.4%: see Fig. 2). Factor 1 separated the land-use systems fallow after crops (FAC), fallow after pasture (FAP) and forest (F) from crops (Cr), pasture (Past) and plantation (Pl). Monte-Carlo test $(P < 0.01)$ simulations exhibited significant differences in the spider assemblage relationships with the land-use systems. The simultaneous comparison of the correlation circle and factorial map arising from the PCA (Fig. 3) showed that the points located for the land uses FAC, FAP and F have strong relationships with three guilds: nocturnal ground hunters (NGH), ground weavers (GW) and ground runners (GR).

DISCUSSION

The results suggest that spider species richness and density decreased with regular disturbance and/or high levels of grazing (Fig. 2). This pattern can be partly explained by
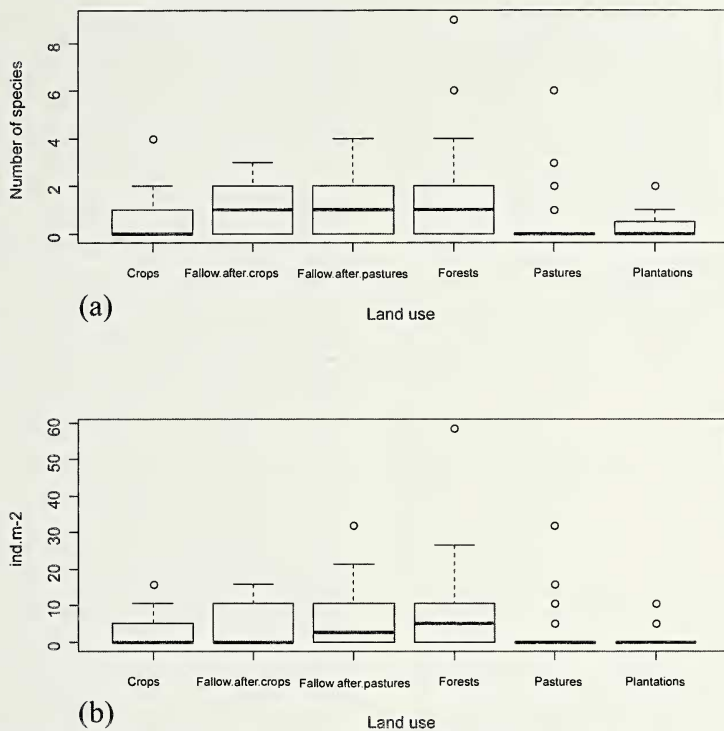
Figure 2.—Total spiders richness (a) and density (b) under different types of land use. The boxplots show the lower quartile, the median and the upper quartile, with whiskers extending to the most extreme data point unless outliers (more than 1.5 times the interquartile range) are present.

Table 2.—Guild classification defined of the spiders sampled by Tropical Soil Biology and Fertility Program method (see Dias et al. 2010). Total number of morphospecies for family/genera on each guild ($n = 10$) is in brackets.

| Guild	Included Taxa
Aerial hunters (AH)	Anyphaenidae (1) – Corinnidae (1): (1) *Trachelas* – Oxyopidae (1): (1) *Oxyopes*
Diurnal aerial ambushers (DAA)	Thomisidae (3): (1) *Bucranium*, (1) *Misumenops*
Diurnal space web weavers (DSWW)	Linyphiidae (8): (1) *Meioneta* – Pholcidae (2): (1) *Mesabolivar*, (1) *Metagonia* – Theridiidae (10): (1) *Chrysso*, (2) *Dipoena*, (2) *Theridion*, (1) *Thwaitesia*
Ground runners (GR)	Corinnidae (7): (1) *Castianeira*, (1) *Corinna*, (2) *Creuga*s, (1) *Mazax*, (1) *Myrmecotypus*, (1) *Orthobula* – Gnaphosidae (3): (1) *Apopyllus*, (2) *Zimiromus* – Lycosidae (1) – Prodidomidae (1): (1) *Lygromma*
Ground weavers (GW)	Dipluridae (1): (1) *Diplura* – Hahniidae (2): (2) *Neohahnia*
Nocturnal aerial ambushers (NAA)	Ctenidae (1): (1) *Acanthoctenus* - Sparassidae (1): (1) *Olios*
Nocturnal ground ambushers (NGA)	Idiopidae (2): (1) *Neocteniza* – Theraphosidae (1)
Nocturnal ground hunters (NGH)	Cyrtaucheniidae (2) – Oonopidae (18): (1) *Brignolia*, (1) *Coxapopha*, (3) *Neoxyphinus*, (1) *Xyccarph* – Palpimanidae (4): (1) *Fernandezina*, (3) *Otiothops* – Salticidae (12) – Tetrablemmidae (1): (1) *Tetrablemma*
Nocturnal space web-weavers (NSW)	Ochyroceratidae (1)
Orb weavers (OW)	Araneidae (13): (3) *Alpaida*, (3) *Mangora*, (2) *Micrathena*, (1) *Spilasma*, (1) *Wagneriana* – Symphytognathidae (1): (1) *Symphytognatha* – Theridiosomatidae (3)

(a)

F2 : 12.3 %

F1: 15.9 %

(b)
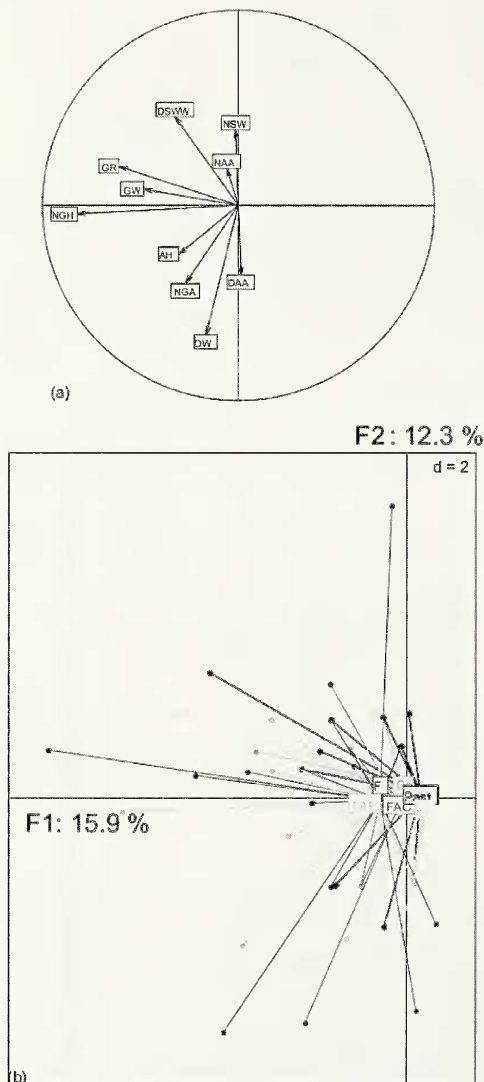
Figure 3.—Principal component analysis (PCA) performed on spider guilds (AH: aerial hunters, DAA: diurnal aerial ambushers, DSWW: diurnal space web weavers, GR: ground weavers, GW: nocturnal ambushers, NAA: nocturnal aerial ambushers, NGA: nocturnal ground ambushers, NGH: nocturnal space web-weavers, NSW: nocturnal space web-weavers, OW: orb weavers) for land use (F: forests, FAC: fallows after crops, FAP: fallows after pastures, Pl: plantations, Past: pastures, Cr: crops). (a) Correlation circle of spider guild density for soil land-use systems. (b) Factorial maps and effect

ecological effects at the vegetation level that are strongly dependent on both the intensity of former arable management and the initial conditions of grassland succession (Van der Putten et al. 2000). Several studies predicted that spider density and diversity would be disproportionally impacted by reduction in plant species richness and habitat complexity (Gibson et al. 1992; Rypstra et al. 1999; Jeanneret et al. 2003; Perner & Malt 2003; Haddad et al. 2009). However, Jeanneret et al. (2003) suggested that the most important local habitat factors are those directly influenced by management practices. It is well known that spiders can exhibit short reaction times to changes in land use (Jeanneret et al. 2003; Perner & Malt 2003) and subsequently to changes in microclimate (Nyffeler & Sunderland 2003; Perner & Malt 2003), soil-moisture (Perner & Malt 2003), litter cover, litter depth and twig cover (Oxbrough et al. 2005). Since the establishment of crops, pastures and plantations makes a significant impact on soil properties, we expected that the soil spiders would be more significantly affected than what was observed. In fact, most similar studies showed that spider species richness decreased due to soil management intensity (Downie et al. 1999; Perner & Malt 2003). Furthermore, the increase in spider diversity on disturbed areas is often constrained, even when natural abiotic conditions seem to be restored (e.g., on secondary forest see Lo-Man-Hung et al. 2008).

Our PCA results separated the land-use systems of forest and fallows (F, FAC, FAP) from those with high anthropogenic soil disturbance (Fig. 3). The PCA also showed that the identification of ecological categories was sufficient to separate the six systems studied, and to indicate which spider guilds were most associated with forest systems. Spider guilds are widely used in environmental management and impact assessment (e.g., Perner & Malt 2003) because of the assumption that the factor affecting a resource in the environment will also impact the whole spider guild (Severinghaus 1981; Simberloff & Dayan 1991). In our study the three guilds (GR, GW, NGH) associated with forest and fallows (F, FAC, FAP) are characterized by spiders that search actively for prey (i.e., Corinnidae, Cyrtaucheniidae, Gnaphosidae, Lycosidae, Oonopidae, Palpimanidae, Prodidomidae, Salticidae and Tetrablemmidae) or are sedentary web-weavers (Dipluridae, Hahniidae) (Höfer & Brescovit 2001; Dias et al. 2010; also see Table 2). Potentially, these three guilds (GR, GW, NGH) favor cryptic and complex habitats; in this study they were significantly represented in the forest and fallows. Also, these guilds seem to be negatively influenced by human impacts on land management, although the lycosids are usually observed in grassland habitats (Jocqué & Alderweireldt 2005). These results suggest that spider guilds can be considered a useful tool for ecological studies, as predicted by other authors (e.g., Gibson et al. 1992; Uetz et al. 1999; Jeanneret et al. 2003). Such information can help to identify their value in land-use areas and evaluate their role in pest management (e.g., Maloney et al. 2003; Nyffeler &

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of soil land-use systems. The dots represent the sites and the color degraded indicates land-use systems as darker to lighter as follows: jet black, black, dark gray, gray, light gray, very light gray for Past, F, FAC, Cr, FAP, Pl, respectively.

Sunderland 2003). Our study suggests that spider guilds can strongly and quickly respond to changes in environmental conditions (as exemplified for wandering spiders by Rego et al. 2005, 2007 and Jocqué et al. 2005). It also highlights the need to prevent anthropogenic changes in ecosystem functioning and ecosystem services, as this is the main factor currently affecting and threatening biodiversity (Chapin et al. 2000).

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